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DEPARTMENT OF COMMERCE

UNITED STATES BUREAU OF MINES
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DIAMOND DRILLING AT THE UNITED VERDE MINE

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INFORMATION CIRCULAR

DEPARTMENT OF COMMERCE - BUREAU OF MINES

DIAMOND DRILLING AT THE UNITED VERDE MINE[1]

By Mayer G. Hansen[2]

INTRODUCTION

A series of papers dealing with diamond drilling practices, compiled in accordance with an outline prepared by engineers of the United States Bureau of Mines, is to be published as information circulars by the bureau. This paper, the first of the series, describes the general practice at the United Verde mine during the last ten years; specific instances cited in the paper refer to 1930, the last year of full operation.

The United Verde copper mine is located at the town of Jerome, Yavapai County, north central Arizona.

The writer wishes to thank Harry J. Mader, diamond drill foreman, for his assistance and cooperation in furnishing data used in this paper, and to acknowledge the permission granted by the management of the United Verde Copper Co. to publish statistics.

Diamond drilling was first undertaken at the United Verde mine in 1904 and was continued into 1906; this early work was done on a contract basis. Diamond drilling was then discontinued until 1913, when the company undertook to do the work on its own account. Drilling on a company basis has continued up to the present time, although for a short period, from 1918 to 1920, contract drilling was carried on simultaneously with company drilling. In all, some 258,000 feet of drilling has been done.

The writer has endeavored to be as accurate and specific as possible in the preparation of this paper, but it is emphatically stated that the drilling at the United Verde Mine is not a mechanical operation; that is, it is impossible to instruct a runner to use a certain bit for any definite footage at any certain speed or rate of advance. It is hoped, however, that the specific descriptions given, covering the practices and experiences at this property, may prove useful to others.

GEOLOGY

In order to compare our drilling conditions with those in other districts, a general resume of the geology, with a brief description of the rocks, will be given. The pre-Cambrian rocks, consisting of volcanic tuffs and flows overlain by a band of siliceous bedded sediments, were rendered schistose by shearing and folding and were intruded by quartz porphyry. A later intrusion of diorite was followed by ore deposition along the concave margin of the diorite, leaving a sulphide mass of which about one-sixth is commercial ore. The more or less crescent shaped sulphide mass measures about 1,100 feet along the strike and averages about 300 feet in width. It lies between a chloritic schist footwall and the diorite. The sulphide becomes harder and more siliceous toward the diorite and is almost all jasper at the diorite contact. In many places the iron sulphides are badly fractured

1 - The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6708."

2 - One of the consulting engineers, U. S. Bureau of Mines, and chief geologist, United Verde Copper Co., Jerome, Ariz.

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broken. The diorite is fresh and hard, with occasional broken, sandy, fault zones. The black schists are very chloritic and have been partially replaced by the sulphides. The quartz porphyry, which intruded the schist, is fresh and hard, although in places along planes of shearing it may be schistose. Near the sulphide body, where acid leaching has had its effect, the porphyry has been altered, softened, and kaolinized.

OBJECT OF DRILLING

The extensive drilling at this property has been done for a number of purposes, as follows:

1. Mineral prospecting: Most "long shot" prospecting, particularly in the outlying areas away from the mine proper, is done by diamond drilling.

2. Outlining known orebodies: After the haulage drift has been driven from the shaft to the orebody, drifts are driven along the sulphide-schist contact, and the level is completely drilled from these footwall drifts before additional prospect or working drifts are driven. This system of drilling is shown in Figure 1.

3. Blocking out ore reserves: A considerable amount of diamond drilling takes place from within the stopes, where, because of the irregularity of the ore shoots, it is frequently necessary to drill to facilitate mining operations.

4. Guiding mine development and workings: Previously in opening up new levels the contact drifts were guided by daily visual inspection and drifts were turned to follow the irregular sulphide-schist contact. This practice obviously involved a certain amount of wasted drifting. On the last lift of levels opened up, a light-weight diamond drill was used to determine the direction of the contact, so that the drift could be driven on definite lines laid out by the engineering staff. This method not only saves in rounds drilled, but permits large-radius curves to be made in the drifts and thus results in lower haulage costs.

5. Geological information: Much drilling is done to determine the contacts of the various geological formations, as well as fault zones.

6. Ventilation: Occasionally raises are driven through the fire area, or adjacent hot ground, wherein the mining work is greatly facilitated by drilling a 2-1/2 or 3 inch hole through which fresh cold air can be blown directly upon the miners.

7. Drainage: The whole mine is equipped with a series of 2-3/4-inch diamond-drill drain holes to control drainage. Although at various times these become plugged temporarily, they are easily chopped out. The system as a whole is considered profitable and successful.

8. Conduits: In the upper levels of the mine, between the 1000-level haulage tunnel and the shovel pit, are a series of ore bins. When the ore becomes wet or when for other reasons ore passers must employ blasting, it is necessary to have a system of blasting signals. An electrical system was installed and the signal wires were dropped through diamond-drill holes, thus saving the expense of running a special line from ore bins to the shaft, and other points on each level.

9. Holes for introducing slime in fire fighting: During outbursts of fire, drifts are bulkheaded off to prevent air circulation, 2-1/4-inch diamond-drill holes are drilled, and slime from the surface plant is pumped to the area involved. This method is particularly advantageous, since holes can be spotted to reach the exact location of the fire or to cover a whole burning stope with a layer of slime.

Method Employed

All drilling is done on company account at a definite base rate for wages, with a bonus dependent upon costs. The method employed in computing bonus is described as follows: (See also Table I, which is a chart for standard rock allowances in terms of dollars per foot, and fig. 2, which is an example of bonus computation.)

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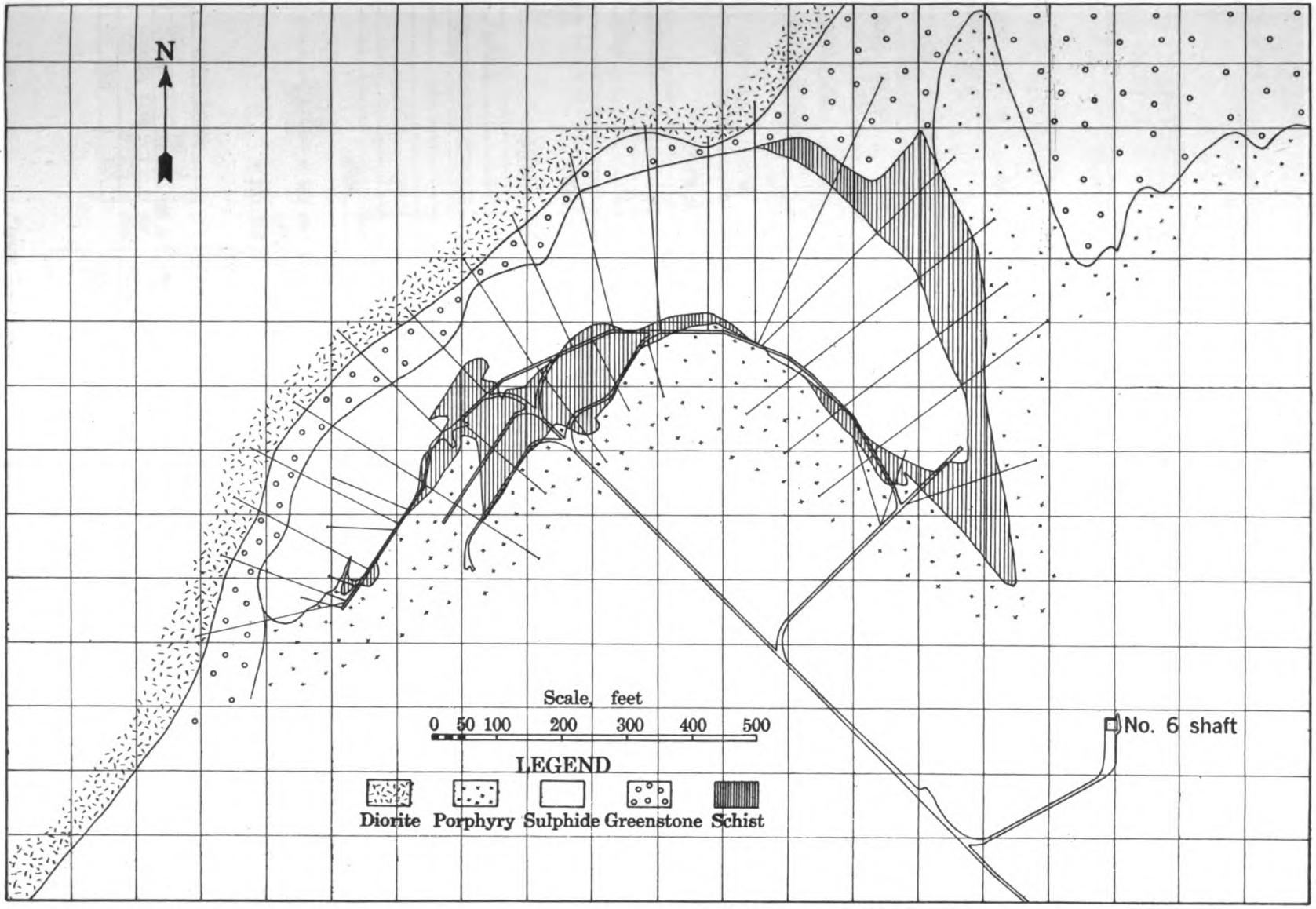

Figure 1.—Typical level showing drill holes

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Drill, Longyear U.G.2-A
Vickers, driller

Debit		
1st class		
2nd		
3rd		
4th		
5th	0.64 @ $48.42	30 99
6th	16.21 @ $6.52	105 69
Total		136 68

$0.42 per foot

Credit	
2nd class	
3rd	
4th	
5th	
Total	None

Debit	$136 68
Credit	None
	$136 68

2700 level; 10-V No. 5; angle, flat; depth drilled 117 feet; "M"

Mader, 3 @ 14	$42	00
Owen, setter 3 @ 6.25	18	75
Vickers, driller 12 @ 5.78	69	36
Rosen, helper 12 @ 4.68	56	16
	186	27
Carbon loss	136	68
	322	95
Moving allowance	—	—
	322	95

2700 level; 11-V No. 3; angle, flat; depth drilled, 209 feet; "M"

Moving allowance	
Vickers	— —
Rosen	— —
	None

Company time	
Vickers	— —
Rosen	— —
	None

Distance	Feet	Class	Factor	Total
105-125	20	Quartz	7.80	171.60
125-133	8	Hard sulphide	3.10	34.10
133-135	2	Quartz	7.80	—
135-138	3	Hard sulphide	3.10	—
138-146	8	Hard greenstone	2.20	17.60
146-196	50	Greenstone	1.45	72.50
196-200	4	Diorite	1.45	5.80
200-222	22	do	1.60	35.20
0- 5	5	Black schist	1.30	6.50
5- 64	59	Sulphide	1.65	97.35
64- 69	5	Quartz	7.65	61.20
69- 74	5	Hard sulphide	2.95	82.60
74- 75	1	Quartz	7.65	
75- 81	6	Hard sulphide	2.95	
81- 82	1	Quartz	7.65	—
82- 85	3	Hard sulphide	2.95	—
85- 86	1	Quartz	7.65	—
86-100	14	Hard sulphide	2.95	—
100-115	15	do	3.10	232.50
115-131	16	Dike	1.45	23.20
131-174	43	Hard sulphide	3.10	—
174-175	1	Quartz	7.80	70.20
175-178	3	Hard sulphide	3.10	—
178-179	1	Quartz	7.80	—
179-183	4	Hard sulphide	3.10	—
183-190	7	Quartz	7.80	—
190-200	10	Hard sulphide	3.10	—
200-202	2	do	3.25	6.50
202-209	7	Quartz	7.95	55.65
	326 feet			$972.50

$\frac{972.50}{322.95}$ = 301 per cent efficiency
= 100 1/2 per cent bonus

Before bonus	
Labor	186 27
Carbon	136 68
Company time	— —
Total	322 95
Per foot	99

$0.42 per foot

Name	Labor	Carbon	Total
Owen	18 84	— —	18 84
Vickers	69 71	— —	69 71
Rosen	56 44	— —	56 44
			144 99

After bonus	
Labor	186 27
Carbon	136 68
Bonus	144 99
Company time	— —
Total	467 94
Per foot	1 44

Figure 2.- Example of bonus computation

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Table 1.- Diamond-drill bonus standard rock allowances in dollars per foot 1/

(As of August 1, 1930)

Depth, feet	Black schist, diorite, bedded sediments, greenstone, dike			Sulphide, quartz porphyry			Hard: Bedded sediments, greenstone			Hard: Sulphide, quartz porphyry, diorite			Quartz		
From-To	Flat +20° to -5°	From +20° to +30°	Over +30° Over -5°	Flat +20° to -5°	From +20° to +30°	Over +30° Over -5°	Flat +20° to -5°	From +20° to +30°	Over +30° Over -5°	Flat +20° to -5°	From +20° to +30°	Over +30° Over -5°	Flat +20° to -5°	From +20° to +30°	Over +30° Over -5°
0- 100	1.30	1.30	1.60	1.65	1.65	1.95	2.05	2.05	2.35	2.95	2.95	3.25	7.65	7.65	7.95
100- 200	1.45	1.45	1.75	1.80	1.80	2.10	2.20	2.20	2.50	3.10	3.10	3.40	7.80	7.80	8.10
200- 300	1.60	1.60	1.90	1.95	1.95	2.25	2.35	2.35	2.65	3.25	3.25	3.55	7.95	7.95	8.25
300- 400	1.75	1.75	2.05	2.10	2.10	2.40	2.50	2.50	2.80	3.40	3.40	3.70	8.10	8.10	8.40
400- 500	1.90	2.05	2.20	2.25	2.40	2.55	2.65	2.80	2.95	3.55	3.70	3.85	8.25	8.40	8.55
500- 600	2.05	2.20	2.35	2.40	2.55	2.70	2.80	2.95	3.10	3.70	3.85	4.00	8.40	8.55	8.70
600- 700	2.20	2.35	2.50	2.55	2.70	2.85	2.95	3.10	3.25	3.85	4.00	4.15	8.55	8.70	8.85
700- 800	2.35	2.50	2.65	2.70	2.85	3.00	3.10	3.25	3.40	4.00	4.15	4.30	8.70	8.85	9.00
800- 900	2.50	2.65	2.80	2.85	3.00	3.15	3.25	3.40	3.55	4.15	4.30	4.45	8.85	9.00	9.15
900-1000	2.65	2.80	2.95	3.00	3.15	3.30	3.40	3.55	3.70	4.30	4.45	4.60	9.00	9.15	9.30
1000-1100	2.80	2.95	3.10	3.15	3.30	3.45	3.55	3.70	3.85	4.45	4.60	4.75	9.15	9.30	9.45
1100-1200	2.95	3.10	3.25	3.30	3.45	3.60	3.70	3.85	4.00	4.60	4.75	4.90	9.30	9.45	9.60
1200-1300	3.10	3.25	3.40	3.45	3.60	3.75	3.85	4.00	4.15	4.75	4.90	5.05	9.45	9.60	9.75
1300-1400	3.25	3.40	3.55	3.60	3.75	3.90	4.00	4.15	4.30	4.90	5.05	5.20	9.60	9.75	9.90
1400-1500	3.40	3.55	3.70	3.75	3.90	4.05	4.15	4.30	4.45	5.05	5.20	5.35	9.75	9.90	10.05
1500-1600	3.55	3.70	3.85	3.90	4.05	4.20	4.30	4.45	4.60	5.20	5.35	5.50	9.90	10.05	10.20
1600-1700	3.70	3.85	4.00	4.05	4.20	4.35	4.45	4.60	4.75	5.35	5.50	5.65	10.05	10.20	10.35
1700-1800	3.85	4.00	4.15	4.20	4.35	4.50	4.60	4.75	4.90	5.50	5.65	5.80	10.20	10.35	10.50
1800-1900	4.00	4.15	4.30	4.35	4.50	4.65	4.75	4.90	5.05	5.65	5.80	5.95	10.35	10.50	10.65
1900-2000	4.15	4.30	4.45	4.50	4.65	4.80	4.90	5.05	5.20	5.80	5.95	6.10	10.50	10.65	10.80

1/ Cement = 1/2 black schist allowance.

M-sized bit = 1.

AS-sized bit = 1-1/2 to 1.

N-sized bit = 2 to 1.

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Efficiency of drilling is determined by the ratio between the rock allowance and the actual carbon and labor costs.

The per cent bonus to be paid, as determined by the per cent efficiency, is to be applied to the labor cost only. One hundred per cent is subtracted from the computed efficiency, the balance divided by two, and 50 per cent of the saving retained by the operators.

A separate bonus account is carried for each machine in operation during the month, and the foreman sees that each operator's card is marked to show to which drill the shift's work is charged. A separate record of the carbon loss of each machine is kept and submitted at the end of the month. Should two shifts be worked on the same machine, the bonus is separated by the runners, and if a bit is used intermittently by different runners, the foreman apportions the losses between them.

The time of the diamond-drill foreman is distributed equally among the different machines according to the drill shifts worked. The setter's time is likewise divided equally among the drills, and he participates in the bonus of each machine.

The diamond-drill bonus standard table is computed to include the labor charge for actual drilling time only. However, moving time is shown on the bonus sheets and an allowance is made on that account. Before each move is made, the diamond-drill foreman prepares a careful estimate of the time required to make the move. This estimated time is used as the time allowance on the bonus statement. If the move is made in less time than is estimated, the time saved improves the showing on bonus for drilling. Delays due to minor repairs, or by reason of negligence on the part of the runner are considered to be part of the actual drilling time. The time employed in taking dip readings is also regarded as part of the actual drilling time. Other time allowances, such as for surveying holes, working in caves where no drilling is possible, and delays due to conditions in the mine for which the drill crew is not responsible, are marked on the time cards as "company time." On special jobs, such as blasting drain holes and surveying old drill holes, a bonus equivalent to the average for the balance of the month is paid. For cementing and drilling through cement, a rock allowance of one-half the schist allowance is used. Special reaming jobs, and drainage, ventilation and conduit hole work, necessitating holes larger than the A size, require a special bonus rate.

ORGANIZATION

The personnel of the diamond-drill department consists of a foreman, two setters, six runners, and six helpers. With the exception of the foreman, all are on day's pay plus bonus. The respective rates are as follows: Setters, $6.25; runners, $5.78; helpers, $4.68. These rates are for periods when the price of copper is 14 cents per pound or less; as the price of copper increases, the base rate increases in accordance with the schedule worked out for western copper mines.

All men are trained locally, starting as helpers. The foreman, in addition to looking after equipment, repairs, supplies, etc., selects the diamonds to be set and decides on the type of bit. Probably most of his time is spent with the runners in teaching them the refinements of drilling.

The length of shift is eight hours from collar to collar of the shaft, including lunch time, in accordance with the laws of the State of Arizona. Two shifts daily are generally worked, day and afternoon, except when for some unusual reason three shifts are necessary. In instances when a drill is connected to an air line supplying many mining machines it is operated on graveyard shift in order not to reduce the available air supply.

Water for drilling is obtained from the town supply from a series of tanks above the mine. The pressure is kept at about 80 pounds. The cost of maintaining pipe lines and the

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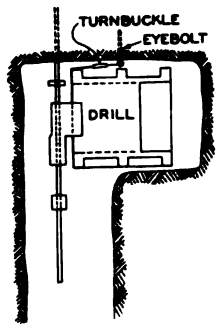

Figure 3.—Method of anchoring drill to prevent twisting

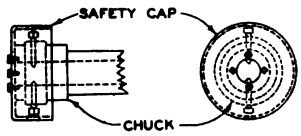

Figure 4.—Safety cap for chucks

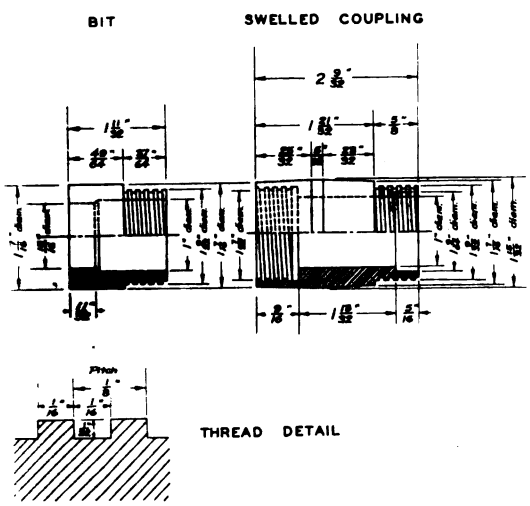

Figure 5.—Special United Verde bit and swelled coupling

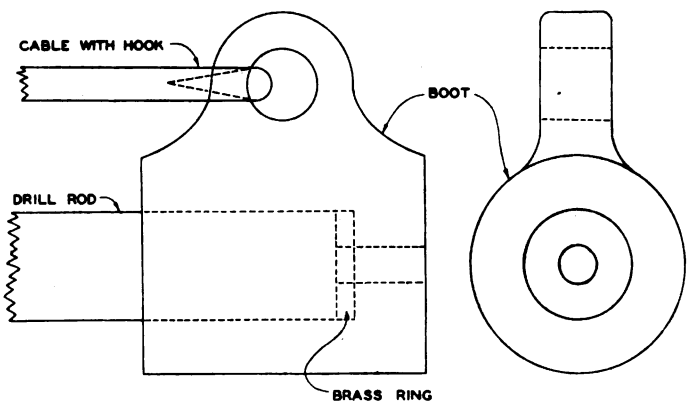

Figure 6.—Boot

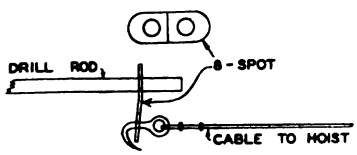

Figure 7.—8-spot

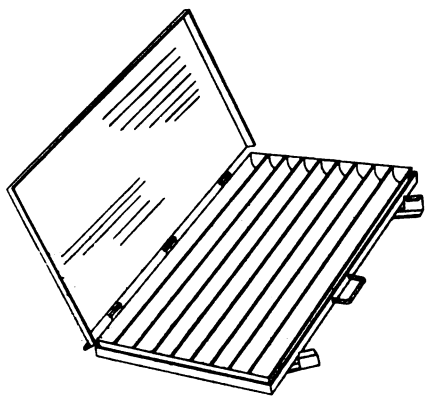

Figure 8.—All-metal core box with removable tray

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cost of the water are kept as a separate mine account, and are distributed in proportion to the number of drill shifts; diamond drills are charged the same as Leyner machines, although the actual consumption of water is greater for diamond drills. The cost of pipe lines averages about 2 cents per foot drilled.

EQUIPMENT AND MACHINERY

At present the United Verde mine is equipped with five machines for underground use, consisting of three Longyear UG machines, one Longyear Junior, and one Sullivan C machine. All are air driven, operating on approximately 90 pounds air pressure. In addition, there is also one Sullivan "21" gasoline rig for surface drilling.

The Sullivan C machine is used for drilling hard rock, large-sized drain holes, and also deep holes, since it is capable of drilling to a depth of 2,500 feet. This machine has a hydraulic swivel head, and has given good service, having drilled 50,000 feet. Tremendous pressures (up to 15,000 lbs.) are used in drilling certain types of rock. This has necessitated a few minor changes in the drill, chiefly in the material used in the construction of the machine. Under such great pressures there is a tendency for the drill to twist out of alignment; this is guarded against by anchoring the drill with chains, turnbuckles, and eyebolts, as indicated in Figure 3.

Two of the Longyear UG machines are mounted on vertical columns. These machines are of the screw-feed type and have a drilling capacity of 900 feet except in hard rock. These machines are used on holes of intermediate depth and also in stopes, into which the drills can be pulled up manways 3 feet square in section. When it is necessary to set up on gob that settles, the drill is set up with screws at the bottom so that it may be jacked up daily without loss of time or danger of drilling out of alignment. Hard rock, such as jasper or siliceous sulphide, tends to cause excessive vibration, which necessitates frequent repairs. This type of machine is also desirable for use in drilling short angle holes up to 400 feet in depth, chiefly for the reason that considerably less station cutting is required. The average consumption of free air for this type of drill amounts to approximately 69,000 cubic feet per working shift.

One of the Longyear UG drills is an upright machine, with a size A hydraulic swivel head. This machine is slightly more flexible than the standard UG drill, and is used chiefly for drilling large-sized drain holes 2-3/4 inches in diameter and about 150 feet in depth A slightly larger station is required for setting up the drill, but its use has an advantage in that the drill is equipped with the A hydraulic swivel head, as well as because of the ready accessibility of the motor and working parts.

For short holes in soft ground the Longyear Junior drill is used. This is a lightweight (500 lbs.) screw feed machine, with a capacity of 250 feet. Several years ago a boxed-in timber slide in manways was adopted as standard for the mine; through them all timber, steel, and supplies are hoisted. These manways are 18 inches square, and in order to take a UG drill into a stope, it was necessary to remove the boxes. Also, there was a need for a drill for short-hole prospecting from drifts, as well as stopes, to replace the long-hole percussion drill which was not entirely satisfactory. This led to the drawing up of specifications covering a light drill of the type desired. These specifications, embodying the desirable features, were submitted to the E. J. Longyear Mfg. Co. and to the Sullivan Machinery Co. for construction. The former company built the "Junior" drill, while the latter built the Baby Turbinair. The advantages of such drills are obvious, and savings are made not only in the cost per foot of diamond drilling, but in guiding development work and stoping operations as well.

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The drive chuck on all drills is voered with a safety device to obviate the danger of catching clothing on chuck nuts. It consists of a round plate welded to a ring and bolted to the face of the chuck. See Figure 4. The chuck is standard and is made up in the company's own shops. Chuck jaws, also made in the company's shops, cost about half the price of manufactured jaws and last about 50 per cent longer.

Drill rods are purchased directly from steel tube mills. A larger-sized tube than the standard-sized rod obtainable from diamond-drill manufacturers is specified. Thus for E rods an outside diameter of 1-3/8 inches, inside diameter of 3/4 inch, carbon content of 0.35 to 0.45 per cent, and manganese content of 0.40 to 0.55 per cent are specified. The life of rods is thus increased by from 300 to 400 per cent, and over a period of a year such rods will average 650 feet of drilling per foot of rod. By purchasing directly from the tube mills and performing all other work incident to the manufacture of the rods locally, there is a saving of from $3 to $3.50 per 10-foot rod. The increase in the outside diameter of the rods decreases vibration very materially, increases core recovery and the life of core barrels, and at the same time causes no added difficulties in passing sludges. The same procedure applies to couplings.

Bits and reaming shells are usually purchased from manufacturers, except for a special type used in all short-hole work. This bit, illustrated in Figure 5, is purchased as tubing from steel mills. It is made from stock 1-7/16 inches in outside diameter by 1/4-inch gage. Since this stock is very nearly the required size, very little machine work is required to cut to inside and outside diameter. The 1/16-inch shoulder on the inside permits setting the inside gage stones flush with the metal, thus affording greater protection to the diamonds. The metal between diamonds wears away so rapidly that no difficulty is experienced from this source. This bit, made up locally, costs $0.28, and effects a saving of approximately 40 per cent. Other advantages of the bit are: Fewer diamonds are required, carbon consumption is decreased, and core recovery is increased. Core barrels used with this bit are purchased from manufacturers, constructed in accordance with specifications furnished them.

For the most part, Mitchell-type core barrels are used, although some other types are used occasionally. Core springs are never used, since it is the usual custom to "dry" or "mud block." It has been found that in drilling broken ground, core springs cause excessive blocking and necessitate frequent pulling of rods.

A few other parts, such as gears, friction plates, etc., are made up locally, and it has been found economical in the manufacture of these parts to use the best grade of steel obtainable.

An effective device called a "boot" is used for handling rods in up holes (see fig. 6). This device is forged from a solid piece of iron in order to lend greater strength to the eye. The center is drilled out slightly larger than the rod, and a copper plate is inserted, the purpose of which is to protect the thread of the rod. A smaller hole is drilled through the back to permit water in the rods to flow out.

For flat holes a so-called "8-spot" is used (see fig. 7), which is fast and efficient. This device is bent at a slight angle, one hole sliding over the rods while the hook engages the other, thus enabling the runners to save more time than when using a hoisting swivel.

Since the mine water system carries pressures of only 50 to 125 pounds, three pumps are maintained to furnish the required water pressure. One pump is a Knowles Special Duplex, 4-1/2 by 3-3/4 by 4 inches, weighing 250 pounds, with a rated capacity of 300 pounds. The other two pumps are Worthington high-pressure types, 4-1/2 by 2-3/4 by 4 inches, duplex, weighing 200 pounds, with a rated capacity of 350 pounds. All pumps require a space of 3 by 1-1/2 feet. Each pump has had a cylinder inserted in the water end which not only increases the pressure, but also permits of rapid and cheap repairing when the cylinders become worn.

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All-metal core boxes, used for transporting drill core to the diamond-drill shop, have been designed. These core boxes consist of a corrugated iron tray carried in an angle-iron frame. On reaching the diamond-drill shop, the tray may be removed from the frame and placed in the rack without rehandling the core. (See fig. 8.) This core box is lighter than the old wooden core box, which quickly became soaked with oil and grease; it is cheaper to construct, lasts many times longer, obviates the necessity of rehandling core, and is more convenient for the person examining the core. The tray is made of No. 26 gage galvanized sheet, pressed to shape with either a corrugating machine or dies with trip hammer. The top of the carrier has a frame made from 3/4-inch angle iron, with welded joints, and covered with No. 26 gage galvanized sheet riveted to the angle-iron frame. The bottom is a frame only, made of 1-inch angle iron with welded joints.

DIAMONDS

The black carbons used at the United Verde mine vary in size from 0.15 to 2.50 carats. After a carbon has been worn down to 0.10 to 0.15 carat it is included with the scrap, which is disposed of by resale or used in making special bits or tools, usually the former.

In 1924 and 1925 the number of stones per bit was increased from 8 up to 12 or 15, which necessitated stones of not more than 1.00 carat for small-sized holes. Stones of 0.50 carat weight were relatively cheap and were purchased whenever the opportunity was afforded. Later the number of stones per bit was further increased up to about thirty-five stones, using all black carbon of 0.25 to 0.50 carat size. During the years 1927 and 1928, when diamond drilling was carried on extensively throughout the world, the price of these smaller stones increased from about $28 per carat to $75 or $85 per carat. This was due chiefly to the demand created by contractors who, in order to fulfill the footage requirements of mining companies, were forced to train drillers hurriedly and use inexperienced men, which unduly increased the carbon consumption. At $70 per carat the use of smaller stones became prohibitive, due to their relatively short life. This was the condition late in 1928, when bort, the reject of the white diamond fields, was introduced to the drillers in this country. The United Verde purchased a small quantity of borts for experimentation, and finally found that, when used in conjunction with black carbon, great economies could be effected. The details of this experimentation are described later.

The black carbons of the best grade are selected according to specific gravity, texture, appearance, shape, and color of the stones. "Naturals," or rounded and tested stones, are avoided, as a rule, chiefly because their texture is hidden from examination, and also because sharp, angular stones, with good cutting edges are required to cut the harder rocks.

As to specific gravity, the choice lies between 3.20 and 3.35, although stones having a specific gravity either above or below this figure are occasionally purchased. It has been found by experience that stones in this range of specific gravity are best suited to the United Verde ground. As a rule, it may be stated that low-gravity carbons are soft and that high-gravity carbons are hard; extremely hard stones (3.45 and up) are brittle and tend to chip, with resulting abnormal losses when cutting hard rock, such as quartz. So-called soft stones with a gravity of around 3.00 will not withstand the drilling of hard, tough rocks, but wear away rapidly and are avoided for this reason.

The smooth natural surface of a stone is generally referred to as the skin. It is of greater density than the inside or matrix of the stone. Thus, when specific gravities are being determined and studied, the amount of skin must be taken into consideration for proper classification. The skin is usually harder and tougher than the matrix. Naturals, or unbroken stones, should therefore be chosen with a relatively higher specific gravity. It has been observed that a natural, with a gravity of about 3.20, lasted remarkably well until the

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skin was worn through, after which the matrix gave way very rapidly. On the other hand, stones having a rough surface and thick skin wear unusually well.

Carbon the texture of which is massive or very fine or close grained is preferable. All black diamonds are crystalline, but the variation in crystallinity is great. Stones made up of crystals relatively large in two dimensions and small in the third have been observed. This type of stone has abnormal losses due to the grains' "flaking off" without wear. Occasionally, stones having two or more distinctly different textures are found, and such stones have a decided plane of weakness at the junction of the differing textures. Slightly porous stones may wear equally well as the more massive stones, although usually the more porous stones have weak walls surrounding the pores, and are to be avoided. When lenticular pores line up one after the other, the result is a plane of weakness.

By appearance is meant flaws or planes of weakness, along which a carbon may break. Examination with a pocket lens frequently reveals slight depressions which may be traced all around a stone, making a closed or practically closed line. Such stones are regarded with suspicion. On other occasions small cracks are actually visible, along which the stone splits in two when subjected to pressure. It occasionally happens that flaws are hidden by the skin, or smooth outside surface of the stone, and are not exposed until after the stone has been run three or four times. The setter must then determine the plane of the flaw and set the stone so as to have the direction of rotation and pressure normal to the plane. It is thus possible to obtain considerable wear from the stone before the smaller segment breaks off.

The best shape to choose is, roughly, that of an octahedron. As previously inferred, smooth, rounded stones are avoided, and stones having more angular shapes, with cutting edges are chosen. There is a difference of opinion among drillers concerning this quality; though there may be a slight increase in the wear on sharp stones, the loss is compensated for in increased footage, thus saving in labor cost, since in diamond drilling the labor cost per foot exceeds, in general, the carbon cost. In jasper, or other extremely hard rocks, sharp stones will gradually become rounded and polished, and finally will stall the motor before advancing farther. In softer rocks, the rounded stones have less wear and are preferable. Also, in drilling broken ground they are better. In the normal stock of carbons on hand, many of the stones become rounded from wear, so that rounded and angular stones are always available, even though only angular stones are purchased.

The color of stones is a factor of less importance than those enumerated above. Deep black, gray, or greenish colored stones apparently are better than yellowish tinted stones, although when the other characteristics are favorable a stone is not rejected on account of color alone. Good thick skins have a vitreous luster, although stones having a dull luster have proved good.

The carbon consumption for each type of rock is shown in the following tabulation. The figures represent the drilling for typical rocks only, and include neither excessively high losses due to accidents nor abnormally low losses. Using the loss for drilling in schist as a standard, a relative factor of hardness is obtained for applying to the losses in drilling other types of rock.

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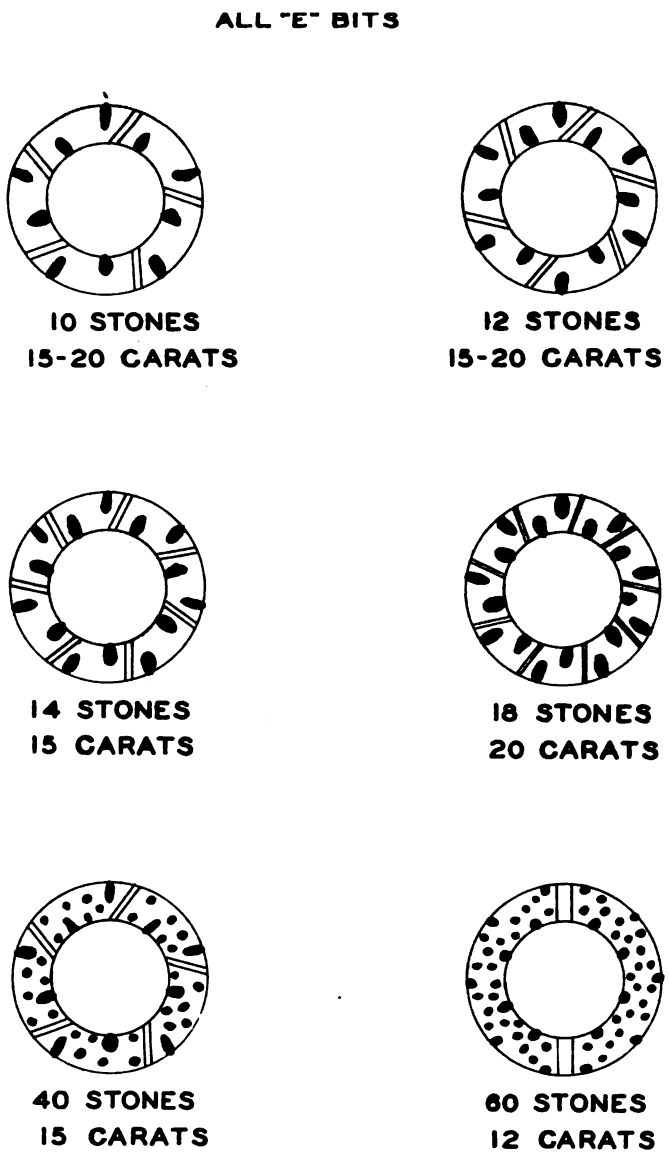

Figure 9.—Typical black-carbon bit settings

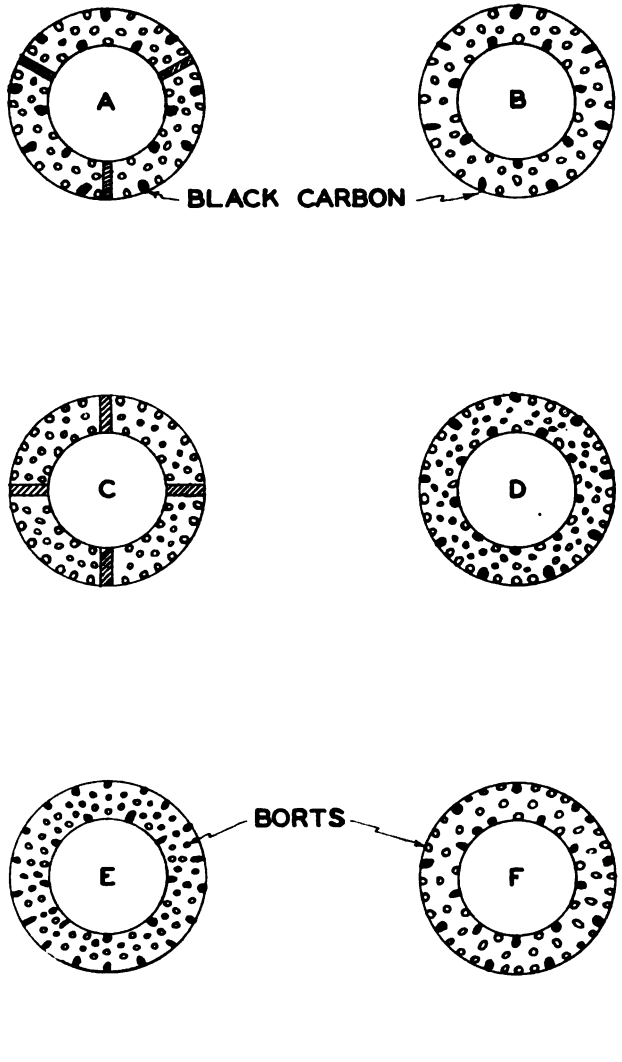

Figure 10.—Typical combination bit settings, using borts and carbons

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Rock	Loss per foot, carats
Black schist	0.002607
Massive sulphide	.004320
Hard massive sulphide	.010244
Quartz porphyry	.004009
Hard quartz porphyry	.009928
Bedded sediments	.001167
Diorite	.003505
Hard diorite	.014781
Greenstone	.002497
Hard greenstone	.005757
Quartz	.032585

Over a period of a year an average of 30 feet per bit is obtained.

Two setters are maintained for six drill crews. Stones are usually top-set and but rarely side-set. Setters make up an average of about two bits per shift, together with the required reaming shells.

For E and A bits, the sizes most frequently used, not less than 12 stones per bit are set, with a maximum of from 35 to 40. Figure 9 shows typical bits set with black carbons for differing types of ground or conditions. Increasing the number of stones per bit has decided advantages. First, the life or footage per bit is increased, and often is doubled, particularly when drilling tough, abrasive ground. Second, it apparently decreases vibration. Third, it materially increases the speed of drilling. Fourth, the strain per stone is so materially decreased as to lower the amount of breaking of stones.

The carbon loss is greater in the first run of a bit than in the succeeding runs, indicating the economy of running a bit as long as it will cut, or until the metal of the bit is so worn as to threaten the pulling out of the stones. When the cutting speed of a bit diminishes materially good practice demands that it be removed to obviate the possibility of breaking, crushing, or polishing the diamonds. A runner is supplied with more bits than he is expected to use in order to prevent time losses in the event of drilling into radically different types of ground. This practice tends to keep the drillers alert and permits the use of dull bits for soft ground and saves, as far as possible, the sharp new bits for hard ground; it also decreases the loss of time due to shortage of bits.

Water grooves are important and should be distributed in a balanced manner across the face of the bit. They should be sufficiently deep to make ample allowance for all cuttings regardless of speed of drilling. Whether the water grooves are spiral, diagonal, or straight up the wall of the bit, makes no apparent difference. Generally they are cut diagonally with a chisel.

Reaming shells or swelled couplings are set with three rows of diamonds, three diamonds to the row. Each successive row increases the clearance 1/64 inch. This practice decreases the load per stone and minimizes breakage and wear, at the same time increasing the life of the reamer considerably. One reamer has carried gage for 2,000 feet in a single hole, while others have lasted for four or five 500-foot holes. The best grade of black carbon, varying in size from 0.25 to 0.75 carats, is used. More recently, bort has successfully replaced black carbon, except for hard or broken formations.

No attempt will be made herein to describe all of the different types or varieties of borts used in diamond drilling. Out of a dozen or so varieties that have been tried, certain types were used successfully and will be described briefly. It is readily admitted that undoubtedly there are other types equally as good and as economical to use as those chosen, and their omission in this brief description is therefore no reflection upon them.

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Clear, unbroken diamonds from the Premier mine, South Africa, were best suited to the conditions at the United Verde mine. They may be smooth and rounded, or in perfect crystal form. Twinned crystals and any stones having a small corner or edge broken off are avoided, as well as those which, when held to the light, show a cloudy appearance indicative of a flaw or crack. Parcel lots are never purchased, nor is the average "mine run" of diamonds; although it is a tedious job, each stone is examined before selection. Actually, after the diamonds have already been graded by the carbon houses into generalized classes, the examination consists merely of turning each diamond so that all sides may be seen and inspected as to the points noted above.

Bort crystals sometimes may be reset three or four times before chipping or breaking. Thus, although the selection may add from 10 to 15 per cent to the cost, one additional reset will save from 20 to 25 per cent of the cost of a diamond.

Usually bort crystals are set individually, in a manner similar to the method used for setting carbons. Frequently, however, all the holes are drilled in the face, small pieces of lead or babbit are placed in the holes, a bort is placed in each hole and lightly set, and then the whole is pressed into position in a 20-ton hydraulic press and caulked tight. This process requires about three hours for setting approximately one hundred (100) stones to the bit.

When bort bits were first used, it was found that the stones would not keep up to gage, but would either break quickly or push into the bit and cause it to bind. Carbons were then used for gage stones, which practice is still adhered to. Such a bit is referred to as a combination bit. Black carbons are considerably tougher and withstand shocks and jars considerably better than the borts, since borts break when unequal pressures are caused by drilling from soft into hard formations, or vice versa.

Various types of combination bits are used for the different types of rock drilled or conditions encountered, and are illustrated in Figure 10. In general, the types used may be described as follows for given conditions:

In broken, cavey formations the largest, most solid black carbons, 2.00 carats in size, will be set and any "track" (borts) used will be so set that the metal-wearing qualities of the rock will not cause the stones to be pulled out. Medium-sized stones will be used for ordinary uniform rocks that are not metal-wearing, and the number of such stones, together with the amount of "track" used, decreases in proportion to the softness of the rock drilled. For siliceous, massive sulphides, siliceous quartz porphyry, or other solid, unbroken, hard rock, small carbons (0.25 to 0.50 kts. size) and small borts (0.066+ to 0.10 kts.) are used, set in a manner similar to that indicated for bits D and E (fig. 10). For drilling hard rocks that are broken and sheared, black carbons only are used, the stones varying in size from 1.25 to 2.00 carats. This type of bit is also used for drilling any ground that is extremely abrasive. For the drilling of schists, soft greenstones, or porphyries, a bit similar to that illustrated by bit B (fig. 10) is used. This bit contains rounded black carbon gage stones, and a smaller number of borts ranging in size from 0.14285 to 0.20 carats. If conditions are particularly good, a bit similar to that illustrated by bit C (fig. 10) may be used. Bit E (fig. 10) is made up from scrap carbon and scrap borts, the individual stones varying in size from 0.05 to 0.15 carats. This is the fastest cutting bit of all, and bits of this type are made up at odd times when scrap is available and when the setters have the normal bit setting taken care of. It is not unusual to have three or four such bits on hand at any given time, ready for use when badly broken, hard ground is encountered.

In addition to the above, saw-toothed bits, as well as plugged and other special types of bits, are cut and set up during odd times, and are thus ready for use during any emergency.

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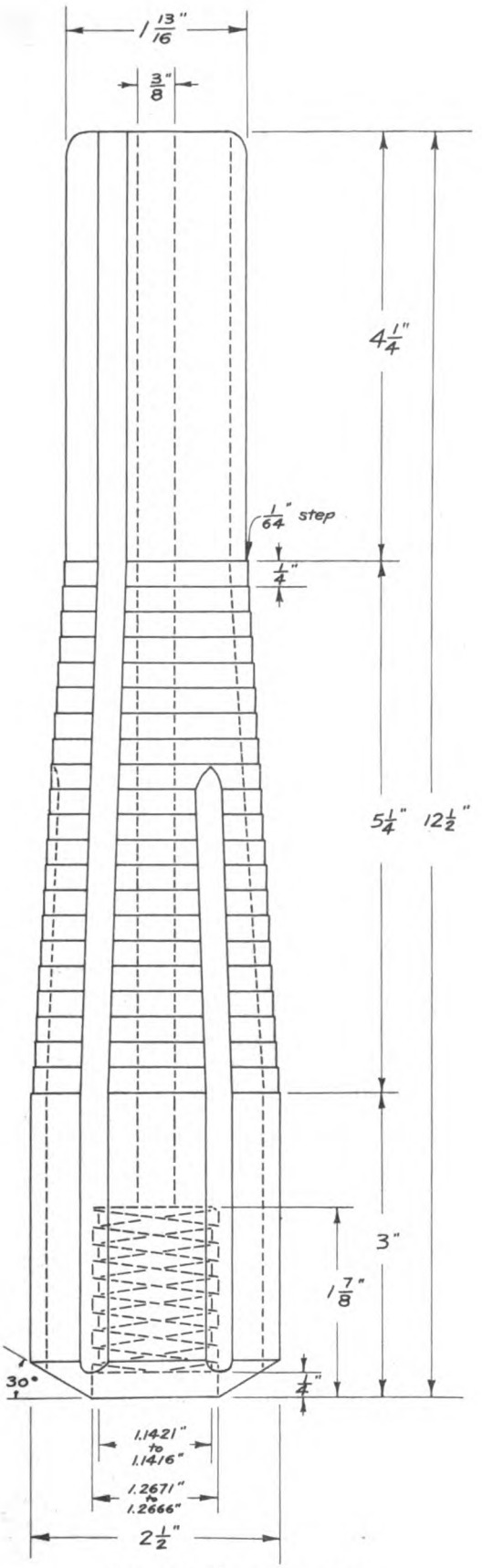

Figure 11.—Tapered reamer

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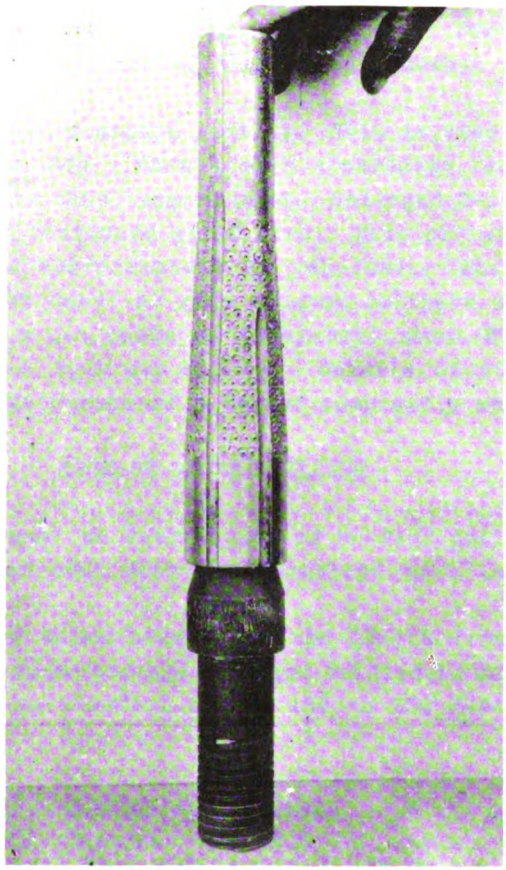

Figure 12.– Tapered reamer

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A special bit, previously mentioned and shown in Figure 5, has been designed locally. This bit has an ES outside diameter and an E inside diameter. A small shoulder 1/16 inch high is left on the inside; the carbon is set flush with the metal so that when run the metal wears away between the stones, thus affording maximum protection for the stones. Since this bit has a small wall, it requires fewer stones; it cuts exceptionally fast, yielding an E core. The shortened length brings water closer to the stones and, by quickly disposing of the cuttings, gives a better core recovery.

Beveled bits, with the face rounded instead of flat, have been tried with moderate success. Their outstanding advantage lies in the fact that in drilling out cement it is almost impossible for the bit to deviate from the line of the hole; further, since they are initially shaped as nearly natural as possible, they offer somewhat greater protection to the diamonds.

A tapered reamer has also been designed locally. This is used for reaming A-sized holes to 2-3/4 inches for various purposes. When a hole apparently requires only one string of casing, a 2-1/2-inch reamer of the same type is used. Salvaged 2-inch pipe from the mine may be set in the hole, and the hole continued at AS size. This obviates the necessity of using high-priced casing, which costs approximately $1 per foot. Bort is used exclusively in tapered reamers, which are set by hand; no gage tool or calipers are used, the stones being set by eye. Reaming with such a bit costs on an average about $0.35 per foot, and is accomplished at a speed of about a foot per minute. Details of such a reamer are shown in Figure 11, and Figure 12 is a photograph of a reamer completely set with borts.

ROCK OR LEDGE DRILLING

For the purposes of this paper no description of surface drilling will be given, since practically all of such work has been done in connection with the exploration of outside properties.

In underground drilling the holes have varied in length from 25 to 2,200 feet. The following tabulation indicates the percentage of holes drilled to various depths, classifying holes from 50 to 150 feet deep as 100-foot holes, 150 to 250 feet deep as 200-foot holes, etc.:

Length	Per cent
0 - 50	2.0
100	9.0
200	17.0
300	11.0
400	12.0
500	12.0
600	12.0
700	9.0
800	4.0
900	5.0
1000 +	7.0

The angles at which holes have been drilled have varied from horizontal to vertical, and may be grouped as follows:

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Angle	Per cent
5° down to 12° up	79
12° up to 25° up	6
Over 5° down, over 25° up	15

Concerning the size of core recovered, 84 per cent has varied from E size to AX size; 14 per cent from AX to N; 2 per cent is of N size or larger.

The percentage of core recovered for all classes of rock drilled has averaged 91.3 per cent. The following tabulation indicates the core recovery classified according to the various types of rock:

Rock	Per cent
Black schist	85.5
Quartz porphyry	88.8
Hard quartz porphyry	94.0
Diorite	87.8
Greenstone	79.2
Hard greenstone	87.1
Massive sulphide	93.6
Hard massive sulphide	95.3
Quartz	88.3

For overcoming troubles in drilling incident to caving, broken, or sandy ground, or other difficulties of a similar nature, cementing is resorted to almost exclusively. In cementing down holes, a thin mixture of neat cement (usually three parts water to one part cement) is pumped in under pressure. A stuffing box, generally a 2-1/2-inch pipe about 30 inches long, is cemented into the hole at the collar and threaded so as to make a tight connection. If great pressures are to be used, the stuffing box is tied to the wall by means of eyebolts and wire. If the ground is caving, cement is introduced through the rods, keeping the bottom end above the top of the cement to avoid the possibility of "cementing in" the rods. When the hole is filled with cement, the pump is connected directly to the stuffing box, and from 300 to 400 pounds pressure is applied. This seals up the rocks for a considerable distance from the hole. Should another cave occur after only one shift of drilling, one of two methods is usually adopted: The first is to pour in cement, lower the rods, and wash the walls of the cemented portion of the hole with clear water until within about 10 feet of the bottom of the previously cemented portion. The water thus used in washing generally has sufficient head to force the cement into the country rock. The second method is to drop cartridges of cement into the hole until a quantity of cement has been introduced sufficient to cover the caved portion. The rods, with the bottom end plugged, are then lowered into the hole, smashing up the cartridges and forcing the cement into the walls.

In drilling short flat holes through sandy, brecciated fault zones, it has been found more satisfactory to cement with cartridges than with a pump, since it frequently happens that the pump continues to wash the loose sand without causing the cement to catch hold and seal up the cave. The cartridges are made of heavy paper similar to the cartridges used for tamping powder in blast holes. From two to four cartridges are pushed down at one time, depending upon the condition of the hole prior to the time of the cave. A maximum of 10 cartridges has been used in some instances. The efficiency of this method depends upon the depth of hole and other conditions; about 500 feet is the maximum depth at which it can be used on account of the abrasive effect of the rock on the paper shells.

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The quantity of cement used depends to a great extent upon the degree to which the ground is broken up or caved. Generally about twice as much cement is used as the computed theoretical volume of the hole; occasionally, however, ten times more than the computed volume has been used.

An effort is made to time the drilling of cement so as to pierce it just after it has set but before it hardens. This permits drilling through 300 to 400 feet of cement in an 8-hour shift. If the ground is badly caved, however, the cement is allowed to harden for about 24 hours.

Both Portland cement and Portland Lumnite quick-setting cement are used. Different rocks have varying effects upon the time required for setting, and this should be determined by experiment prior to cementing. In about 70 per cent of the instances when it was necessary to cement, normal Portland cement was used; in about 20 per cent of the instances 50-50 mixtures of Portland and quick-setting cement were used; in the remaining 10 per cent of the instances quick-setting cement only was used. Quick-setting cement is used in cementing small caves from 2 to 10 feet wide, where good ground has been encountered immediately before the cave. Under such conditions it is improbable that the drill would deviate from the course of the hole, which might happen if the country rock is softer than the hardened cement. Quick-setting cement is also used in the case of sandy, loose, or talcky ground. It may be mentioned that only clean water should be used for mixing cement. Acid water or high rock temperatures may prevent the setting of cement. Also, films of grease or oil on the walls of the hole may prevent adhesion of cement.

The use of casing is rarely resorted to, as may be inferred, although a string is kept on hand and ready for use in instances when it is impossible to cement. At present 800 feet of size EX and 600 feet of size AX casing are on hand.

OPERATION

As previously stated, both hydraulic and screw feed machines are used. The hydraulic-feed machine is much to be preferred; the advantages of this type of machine are: (1) Its flexibility, by means of which the rate of advance is varied according to the character of the rock being drilled; (2) the bit is cushioned to a certain extent; and (3) the machine as a whole requires less upkeep and repair. A distinct disadvantage of the screw-feed type of machine lies in the fact that in drilling non-uniform ground it is necessary to reduce the speed in order to be on the safe side as to carbon wear. This type of machine also must bear greater upkeep and repair charges. It does, however, have certain advantages, among which are: (1) The runner is apprised of changes in the nature of the ground that may be taking place due to the constant pressure on the bit; (2) this type of machine cuts the harder rocks, such as jasper, at the expense of carbon, whereas the hydraulic type of machine, with its cushioning effect on the bit, has a tendency to polish the bit and thus to cause carbon loss but without footage to show for it.

In general, for drilling soft ground, such as schist, it has been found best to reduce the revolutions per minute and increase the pressure and rate of advance. To obviate the danger of "mudding in" and sticking the bit, care should be exercised to see that the bit has enough water grooves and that the water pressure is sufficient to remove the cuttings as fast as they are formed. In drilling ordinary uniform ground, the limits of pressure and revolutions per minute of the machine are determined by the sound of the motor and the "feel" of the rods; that is, if the motor turns over erratically and labors, or is jerky, too much pressure is being used. Vibration, the greatest single cause of excessive carbon wear, is determined by feeling the rods ahead of the chuck with the hand. Variation in the rate of advance will reduce vibration.

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In extremely hard ground best results are obtained by reversing the drilling procedure for soft ground - that is, by increasing the revolutions per minute and decreasing the rate of advance and pressure.

The Longyear UG screw-feed machine is usually operated in the 300 gear, giving an advance of about 7 feet per hour, although the speed may be varied to give from 7 to 12 feet per hour; this includes the handling of rods. In an 8-hour shift on a new hole, the footage will range between 40 and 70 feet, depending upon the type of ground being drilled.

When it is desired to drill a prospect hole to a depth of not over 800 feet, ES bits are used - that is, bits with outside diameters of 1-29/64 inches and core diameters of 13/16 inch. When it is desired to drill to depths of more than 800 feet, the hole is stated with E size bits, with outside diameters of 1-35/64 inches and core diameters of 15/16 inch; gradually the size is diminished until the hole finishes with ES size. When it is desired to drill a hole to a depth only slightly beyond the so-called 800-foot limit, it is started with ES-sized bits set oversize.

The process of reaming is so variable, and depends so much upon the conditions surrounding each instance, that no description will be given here. As has been previously mentioned a special type of reamer has been devised that will enlarge a hole from 1-13/16 inches up to 2-3/4 inches.

The following tabulation, covering a total of 1,200 shifts, enumerates the delays to normal drilling, as well as the per cent of the total due to each cause. On acount of the 8-hour collar-to-collar law in effect in this State, an average of one hour is taken for the time required for reaching the job and returning to the portal of the tunnel, plus a half hour allowance for lunch. The tabulation is thus based on a 6-1/2-hour shift.

Cause of delay	Per cent of total time available for drilling
1. Moving	17.02
2. Cementing	3.55
3. Reaming	.56
4. Caving ground	.73
5. Fishing for rods or bits	.94
6. Repairs	1.54
7. Bits	1.25
8. Air and water	1.73
9. Supplies	.89
10. Surveying holes and engineering	.36
11. Mine department	1.46
12. Drill shop and equipment	1.09
Total	31.12

The following tabulation indicates the detailed cost per foot, which will bear some explanation. Labor includes not only the wages of the members of the diamond-drill department but also includes miscellaneous charges for labor performed by other departments, such as special piping jobs, the work of roustabout men, etc. Certain items, such as supplies and repairs, carry their proportion of overhead, which is not shown separately. Casing and reaming costs have been included in the drilling costs under labor and carbons. Drill-rod wear and depreciation is included under supplies. Supervision by the geological department is not distributed into the diamond-drilling account. All machines, rods, and other equipment are charged out as supplies during the year in which they are purchased.

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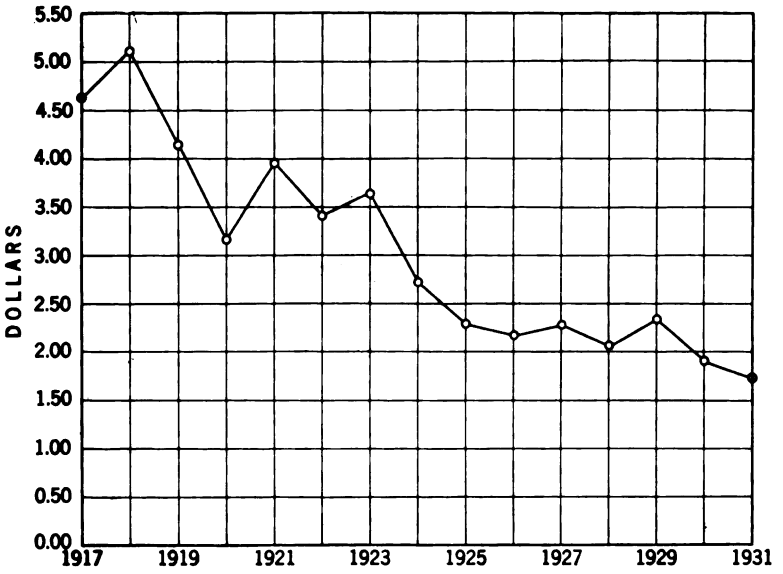

Figure 13.—Diamond drilling total cost per foot

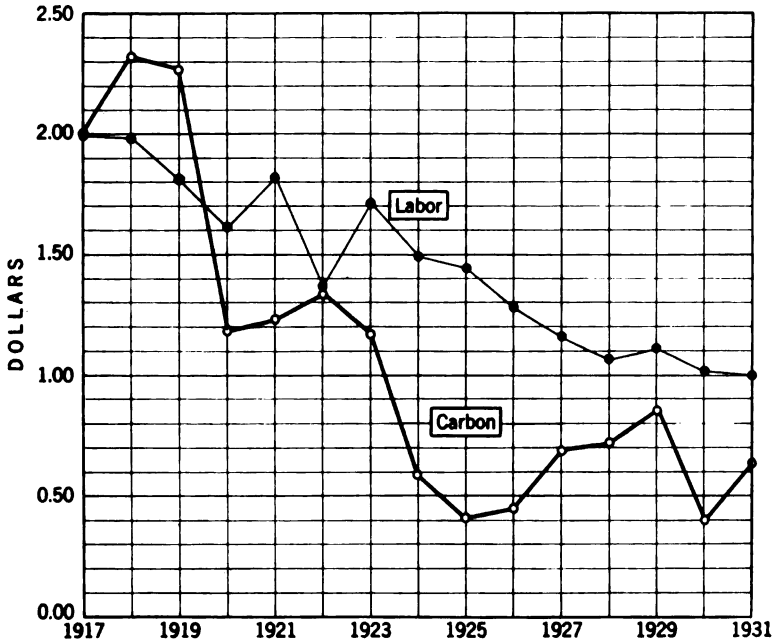

Figure 14.—Diamond drilling carbon and labor cost per foot

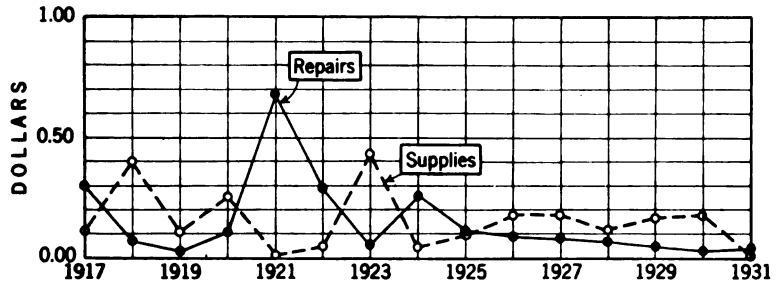

Figure 15.—Diamond drilling supply and repair costs per foot

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	Cost per foot
Labor	$0.97
Carbons	.40
Liability insurance	.05
Power	.02
Water	.02
Supplies	.18
Repairs and replacements	.07
Cutting stations and miscellaneous	.10
Total	1.81

Graphic charts, indicating the total cost per foot and the costs per foot segregated as to certain items, are shown in Figures 13, 14, and 15. These charts cover the period from 1917 through 1931.

Special Features

Unusual conditions or difficulties are frequently encountered. The following description of two such cases may be of interest.

In one instance, the rods had twisted off and the hole subsequently caved, thus bending the rods out of alignment with the hole. The hole had been drilled partly in a very soft, altered dike and partly in massive sulphide. After the break and before the runner was aware of what had happened, he had continued to push the rods in and had thus bent the first section. An ES-sized "pigtail" would not grip the rods, but did indicate that the first section at the point of the break was bent into a compound curve. The ES-sized hole was reamed to an N size and cased. ES rods with pigtail were then inserted inside the casing, and the broken segment was firmly gripped beyond the point of bending. While the broken segment was thus held, the casing, to which a special tool-steel bit had been attached, was advanced to cut off the bent portion, thus permitting the broken segment to enter the casing. The casing was then removed, a diamond bit attached, and the casing again sent into the hole to ream over the rods until the cave was passed. It then was possible to pull out the broken segment without the loss of diamonds.

Another type of accident that sometimes occurs is the pulling out of stones in excessively broken ground. Stones lost in this way are sometimes recovered by the use of a reaming shell, which is cut in two, and the water holes are enlarged to approximately fit the size of the lost stone. These holes are filled with grease or wax, and the bit and rods are lowered into the hole and run in and out, rotating all the while, until the diamond finally lodges in one of the holes and is thus recovered. If it so happens, however, that the hole is making a large amount of water, the stone may be washed away from the bottom, and would therefore not be picked up.

Deflection of Holes

Practically all holes except short ones deviate from the planned or desired bearing. This deviation is caused in part by drilling pressure resulting in a 2-point suspension - bit end and machine end - with the attendant sag in rods, and in part by rotation, changes in ground, schistosity, rock slips, and faults. Observation has shown that in a flat hole, the first 200 feet are quite straight, the second 200-feet show the maximum amount of deflection, and the rest of the hole may or may not be straight. Vertical down holes generally tend to follow the banding, bedding, schistosity, rock contacts, or faults through which they pass.

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Holes inclined upward or downward not more than 50° have a tendency to flatten more often than not, while holes drilled at an angle of more than 50° have a tendency to steepen. Flat holes that cut the schistosity, banding, contacts, or other structures at an angle tend to turn in a direction normal to them.

All holes of importance are surveyed with the Wright[3] surveying compass and tool. This is a photographic machine; it is fast to operate and apparently is accurate and economical. Dip readings taken with this machine are checked occasionally by the well-known method of using etching glass tubes with hydrofluoric acid.

Drill holes are rarely deflected deliberately, and then only if ore happens to have been encountered in a "long-shot" (prospecting) hole. If it is desired to check assay values or determine the extent or continuity of ore, a wedge is placed in the hole 100 to 150 feet ahead of the ore, without regard to the direction of deflection.

Drain holes between levels occasionally fail to connect because of deflection. The position of a hole that has thus failed to connect is determined by setting up an electromagnet in the hole at the depth at which the drill should have holed through intothe drift, and measuring the deflection on a compass needle at several points in the drift. The process consists of setting up a transit at 2-foot intervals along the drift and at a measured height above the floor, and determining the normal bearing. A bar of soft iron 1 inch in diameter and about 2 feet long, wrapped with about 20 turns of wire, is pushed into the hole ahead of two lengths of brass rods. The wires are connected to batteries of about one-third the capacity of a mine locomotive battery, and the transit compass is reread. The polarity of the electromagnet is then reversed, another compass reading is taken, and the difference and direction of difference between the normal and the induced magnetic fields is determined for each set-up of the transit. The two points of maximum difference can then be determined; the hole is assumed to lie on a line normal to the drift at a point midway between these two points of maximum compass deflection. A drift round is shot into the wall with this line as the center. If two such drift rounds fail to locate the lost hole, a torpedo is made 1-1/2 inches in diameter, 40 to 48 inches in length, and containing about 20 sticks of 60 per cent dynamite, with the paper wrapping removed. Two electric blasting caps are inserted, a wooden plug is screwed to the end of the torpedo, and a spring is attached to the wooden plug to prevent movement after the rods have been removed. The torpedo is then pushed into the hole to a point slightly beyond the theoretical point where the hole should have intersected the drift. After the rods have been removed, the charge is detonated with an electric blasting machine, which should be located a reasonable distance away from the collar of the hole and not in line with it.

GEOLOGICAL NOTES AND SAMPLING

The form used by the runners in making daily reports of their work is illustraed in Figure 16.

The form used in describing cores recovered is illustrated in Figure 17. As a supplement to geological descriptions, small pieces of core not over 3/8 inch in length are taken at intervals of about 10 feet, except where changes in formation or unusual conditions are encountered, or when for other special reasons a shorter interval is desirable. These specimens, labeled with the distance in feet from the collar of the hole to the point from which they were taken, are kept in a special cabinet for reference and constitute a permanent actual record of the rock drilled.

3 - Lawrence B. Wright, chief geologist, Homestake Mining Co., Lead, S. Dak.

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The core is regularly sampled at 5-foot intervals, all of the core being used for the sample except the small pieces taken for permanent record. The only departure from the 5-foot sample interval is made when sharp contacts mark the boundary between ore and waste. Three per cent (3.00%) copper is considered the minimum grade of ore that economically can be mined. The barren cores from holes drilled for geological information are not sampled. Sludge samples are taken only when the drilling has encountered mineralization; these are kept separate by runs, and the hole is washed out completely at the start of each run. Following is the method of combining the assays of core and sludge samples. The same procedure is followed in making calculations for holes of different sizes.

Method of calculating combined assays
diamond-drill core and sludge samples

Inside area (core) ES-sized hole	square inches	= 0.645
Outside area (total)	do.	= 1.767
Area in sludge with 100 per cent core recovery	do.	= 1.122

Core recovery, per cent	Net core assay, per cent	Net sludge assay, per cent
100	36	64
95	34	66
90	32	68
85	31	69
80	29	71
75	27	73
70	25	75
65	23	77
60	22	78
55	20	80
50	18	82
45	16	84
40	14	86
35	13	87
30	11	89
25	9	91
20	7	93
15	5	95
10	4	96
5	2	98

A = Percentage of core recovery
B = Weight of core assay
C = Percentage of Cu in core
D = Weight of sludge assay (100 - B)
E = Percentage of Cu in sludge

Formula: Combined assay = B x C + D x E

Example: A = 70 per cent; B = 25 per cent; C = 6.4 per cent; D = 75 per cent; E = 2.8 per cent; Combined assay = 0.25 x 6.4 + 0.75 x 2.8 = 3.7 per cent copper.

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In one instance holes yielding 2-inch cores were drilled through an orebody to provide a 2-ton sample for mill testing. This sample could not be obtained in any other manner, since drifts and other workings had not cut this particular orebody sufficiently to furnish a representative sample for a test run. The sample obtained in this manner, however, probably was accurately representative of the ore in question.

RESULTS OF DRILLING

The accuracy of core and sludge samples compares very favorably with the results of subsequent development; such samples may run slightly higher or lower in grade than the ore as actually mined, depending upon the rock cut. On the whole, however, this difference is so slight as to be almost imperceptible. The cost of diamond drilling is so much less than the cost of driving underground headings to obtain the same information that conventional underground exploration methods are not economical for the purposes to which diamond drilling is applied. Diamond drilling is considered a necessary adjunct to the United Verde operation, and on the basis of the information obtained and its utility to the mine as a whole it has been an economical and successful undertaking.

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UNITED VERDE COPPER CO.
Jerome, Ariz.

DAILY DIAMOND-DRILL RECORD

Drill ———— Date ———— Shift————

Level ———— Hole ———— Block————

Floor ———— Angle ————

Depth at end of shift ————

Depth at start of shift ————

Feet drilled ————

Core recovery ————

Time lost and cause————

Feet Formation

Kind of rock

Remarks ————

Runner ———— Helper ————

Figure 16.— Runner's daily report form

Feet drilled	Feet core	% core	Core Feet	Core %Cu	Comb. % Cu	Avr. % Cu	Form	Sludge Feet samp.	Sludge % Cu

DIAMOND-DRILL HOLE RECORD
————Level ———— Block Hole No. ———— Page ——Stope ——Fl.——
Bearing ———— Angle ———— Elev. of collar ———— Plotted ————
Coordinates - Start ———————— End ————
Begun ———————— Completed ————

Figure 17.- Diamond-drill hole record form

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